iii. Refrigerator Cycle Calculations

The process requirements for the RHIC helium refrigerator to meet the baseline heat load are presented here. Other cases with higher loads have been studied, and the results may be found in Tech Note AD/RHIC/RD-74, along with details of this calculation. The compressor flow required for the refrigerator to meet the baseline load is approximately 60% of the installed compressor capacity. The reference schematic for these calculations is shown in Fig. 3-3. The calculated process state points for this case are given in Tables 3-7A and 3-7B. As shown in Table 3-7B, the calculated electric power required for the main compressors to satisfy this operating point is 8.8 MW.
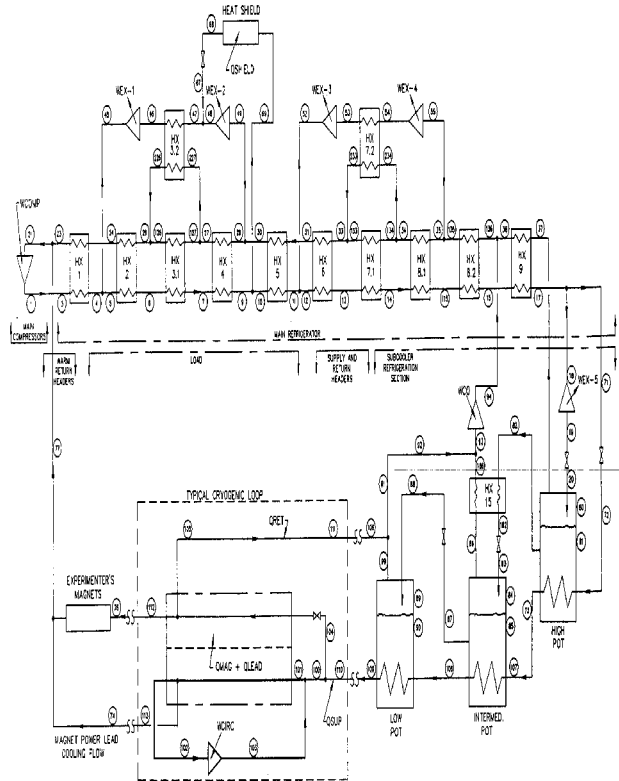

Fig. 3-3. RHIC refrigerator schematic.

Table 3-7A.   Process Requirement for RHIC Refrigerator at Design Heat Load

Fluid Properties and Flow Rates

Pressure (bar), Temperature (K), Enthalpy (J/g) and Flow Rate (g/s)

PT	Pres. bar	Temp. K	Enthal. J/g	Flow g/s	PT	Pres. bar	Temp. K	Enthal. J/g	Flow g/s
1	17.25	305.00	1604.33	2486.45	3	16.40	305.00	1604.04	2486.45
4	16.28	180.00	954.62	2486.45	5	16.28	180.00	954.62	1853.27
6	16.18	151.78	807.86	1853.27	7	16.00	65.84	359.22	1853.27
9	15.68	40.00	222.00	1853.27	10	15.67	40.00	222.00	1448.95
11	15.64	25.00	139.41	1448.95	12	15.64	25.00	139.41	647.81
13	15.61	20.73	114.75	647.81	14	15.57	12.45	63.23	647.81
115	15.56	8.13	32.79	647.81	15	15.54	5.44	20.37	647.81
17	15.53	5.02	18.88	647.81	18	15.49	5.03	18.88	259.04
19	2.50	4.98	14.31	259.04	20	1.43	4.63	14.31	259.04
80	1.42	4.62	29.51	33.40	81	1.42	4.62	12.06	225.64
82	1.42	4.62	12.06	71.28	182	1.41	4.61	12.06	71.28
83	1.35	4.56	12.06	71.28	84	1.35	4.56	29.68	1.67
85	1.35	4.56	11.64	69.61	86	1.35	4.56	29.68	23.48
186	.92	4.13	29.68	23.48	87	1.35	4.56	11.64	47.80
88	.93	4.14	11.64	47.80	89	.93	4.14	30.15	5.31
90	.93	4.14	9.32	42.49	99	.93	4.14	30.15	47.80
91	.92	4.22	30.84	343.56	92	.92	4.21	30.84	343.56
93	.92	4.20	30.77	367.04	94	1.40	5.24	35.62	367.04
21	1.05	302.01	1583.34	2486.45	23	1.10	302.00	1583.34	2393.45
24	1.14	172.02	908.29	2393.45	26	1.17	149.88	793.30	2393.45
126	1.17	149.88	793.30	1783.57	127	1.24	60.00	326.38	1783.57
226	1.17	149.88	793.30	609.88	227	1.24	60.00	326.38	609.88
27	1.24	60.00	326.38	2393.45	29	1.29	39.42	219.34	2393.45
30	1.31	39.42	219.34	1355.95	31	1.32	22.50	130.91	1355.95
33	1.33	20.13	118.44	1355.95	133	1.33	20.13	118.44	626.21
134	1.35	10.06	64.67	626.21	233	1.33	20.13	118.44	729.75
234	1.35	10.06	64.67	729.75	34	1.35	10.06	64.67	1355.95
35	1.39	7.50	50.13	1355.95	135	1.39	7.50	50.13	554.81
136	1.40	5.24	35.62	554.81	36	1.40	5.24	35.62	187.77
37	1.41	4.62	29.51	187.77	45	16.23	180.00	954.62	633.18
46	9.00	151.78	805.66	633.18	47	8.90	65.84	358.03	633.18
48	8.86	65.84	358.03	1037.49	49	1.30	39.42	219.34	1037.49
52	15.58	25.00	139.41	801.15	53	8.00	20.73	118.09	801.15
54	7.92	12.45	69.49	801.15	55	1.41	7.50	50.13	801.15
67	8.90	65.84	358.03	404.32	68	9.67	65.81	358.03	404.32
69	15.67	40.00	222.00	404.32	71	15.49	5.03	18.88	388.77
72	5.13	5.76	18.88	388.77	73	5.03	4.67	12.82	388.77
74	4.58	4.50	11.94	48.00	76	.98	4.20	11.02	45.00
77	1.07	302.00	1583.33	93.00	100	5.00	6.56	27.69	24.00
101	5.00	5.21	15.50	124.00	102	4.58	4.50	11.94	100.00
103	5.00	4.62	12.57	100.00	104	5.01	4.19	11.02	170.38
105	.98	4.20	30.14	147.88	106	.93	4.23	30.95	295.77
107	5.03	4.67	12.82	388.77	108	5.02	4.61	12.55	388.77
109	5.01	4.19	11.02	388.77	110	5.01	4.19	11.02	194.38
111	.93	4.23	30.95	147.88	112	.98	4.20	11.02	22.50
113	4.58	4.50	11.94	24.00					

Table 3-7B.   Process Requirement for RHIC Refrigerator at Design Heat Load

PROGRAM RHIC

Calculate performance of RHIC helium refrigerator which utilizes 5 expanders and 1 cold vacuum compressor. Circulating compressors located in the rings are used to circulate the cold helium through the magnets.

SUMMARY OF SYSTEM PARAMETERS

Refrigeration (W)					Mass Flow (g/s)	
QMAG	QLEAD	QSUP	QRET	QSHLD.	F74	F76
2875.	1855.	800.	240.	55000.	48.	45.

ESTIMATED HEAT LEAKS IN THE HEAT EXCHANGERS (W)

HX1	HX2	HX3	HX4	HX5	HX6	HX7	HX8	HX9	H.POT	I.POT	L.POT
950.	3240.	2670.	1880.	240.	410.	600.	520.	180.	340.	290.	290.

HEAT EXCHANGER PARAMETERS

Heat Exchanger	High P Flow g/s	Low P Flow g/s	Cmin/Cmax	Effectiveness Ratio	Required AU kW/K	NTU	Design AU kW/K
1.0	2485.4	2393.4	1.040	.977	311.0	25.51	684.0
2.0	1853.3	2393.4	1.274	.937	64.2	6.66	183.1
3.1	1853.3	1703.6	1.046	.979	240.6	25.66	533.8
3.2	1853.3	2393.4	1.255	.978	114.3	13.40	280.4
4.0	1449.0	1356.0	1.128	.967	94.9	13.40	201.2
6.0	647.8	1356.0	1.799	.873	12.7	3.38	58.4
6.1	647.8	526.2	1.216	.944	32.6	7.96	127.8
7.2	801.1	729.7	1.216	.944	31.0	7.95	148.5
8.1	647.8	1356.0	1.689	.895	14.0	4.68	61.8
9.0	647.8	187.8	1.484	.807	3.1	1.69	11.5

EXPANDER PARAMETERS

Turbine	Pin bar	Pout bar	Tin K	Tout K	Flow g/s	ETA	Work W
1.0	16.23	9.00	180.00	151.78	633.	.75	94317.
2.0	8.86	1.30	65.84	39.42	1037.	.75	143895.
3.0	15.58	8.00	25.00	20.73	801.	.70	170080.
4.0	7.92	1.41	12.48	7.50	801.	.70	15512.
5.0	15.49	2.50	5.03	4.98	259.	.50	1184.

COMPRESSOR PARAMETERS

Comp.	Isother. Eff.	Adiabatic Eff.	Pin bar	Pout bar	Tin K	Tout K	Flow g/s	Work kW	Work hp	IN VOL F1 ACFM	IN Densi. g/cm³	Pres Ratio
Main	.50		1.05	17.25	302.0	305.0	2486.	8803.	11801.			
Cold	.60	.92	1.40	4.20	5.24	367.0	1.779	2.385		52.4	.0148	1.531
Circu.	.50		4.58	5.00	4.50	4.62	100.0	.063	.084			.136

One circulating compressor is required in each of the 2 cryogenic loops

LOAD SUMMARY

	Primary Load Supply	Return	Secondary Load Supply	Return
Flow Rate (g/s)	388.77	295.77	404.32	404.32
Pressure (bar)	5.01	4.23	18.67	9.67
Temperature (K)	4.19		40.00	65.81
Enthalpy (J/g)	11.02	30.95	222.00	358.03